Automatic Management of TurboMode

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Executive Summary

- **TurboMode** overclocks cores to exhaust thermal budget
  - An important performance feature of multi-core x86 servers
- **Challenge:** turbomode does not always benefit workloads
  - Naively turning TurboMode on often leads to high energy waste
- **Solution:** predictive model to manage TurboMode (on/off)
  - Using machine learning on performance counter data
  - Eliminates negative cases, boosts ED and ED^2 by 47% and 68%

What is TurboMode (TM)?

- Dynamic overclocking of cores to exhaust thermal budget
  - Matches actual power consumption to max design TDP
  - Big performance gains: up to 60% frequency boost
  - Found on all modern x86 multi-cores

- TurboMode control
  - Black-box HW control decides when and how much to overclock
  - SW has limited control: can only turn TurboMode on/off

Characterizing TurboMode

- Evaluate the effects of TM across the board
  - Efficiency metrics: EDP, ED^2P, throughput/W, throughput/$, …
  - Many hardware platforms: Intel/AMD, server/notebook
  - Many workloads: SpecCPU, SpecPower, websearch, …

- Characterization
  - Run with TurboMode on and TM off
  - Compare impact on all of efficiency metrics

Efficiency Metrics

- Guidelines
  - We all care about performance and energy consumption
  - Capture both latency and throughput workloads
- Metric recap
  - **ED**: latency & energy
  - **ED^2**: latency & energy, more weighted towards latency (think servers)
  - **Throughput/W**: throughput & energy
  - **Throughput/$**: throughput & cost efficiency (think datacenter TCO)

Evaluation Hardware

- Intel Sandy Bridge server **[SBServer]**: 19% max boost
- Intel Sandy Bridge mobile **[SBMobile]**: 44% max boost
- AMD Interlagos **[ILServer]**: 59% max boost
- Intel Ivy Bridge server **[IBServer]**: 12% max boost
- Intel Haswell server **[Hserver]**: 13% max boost

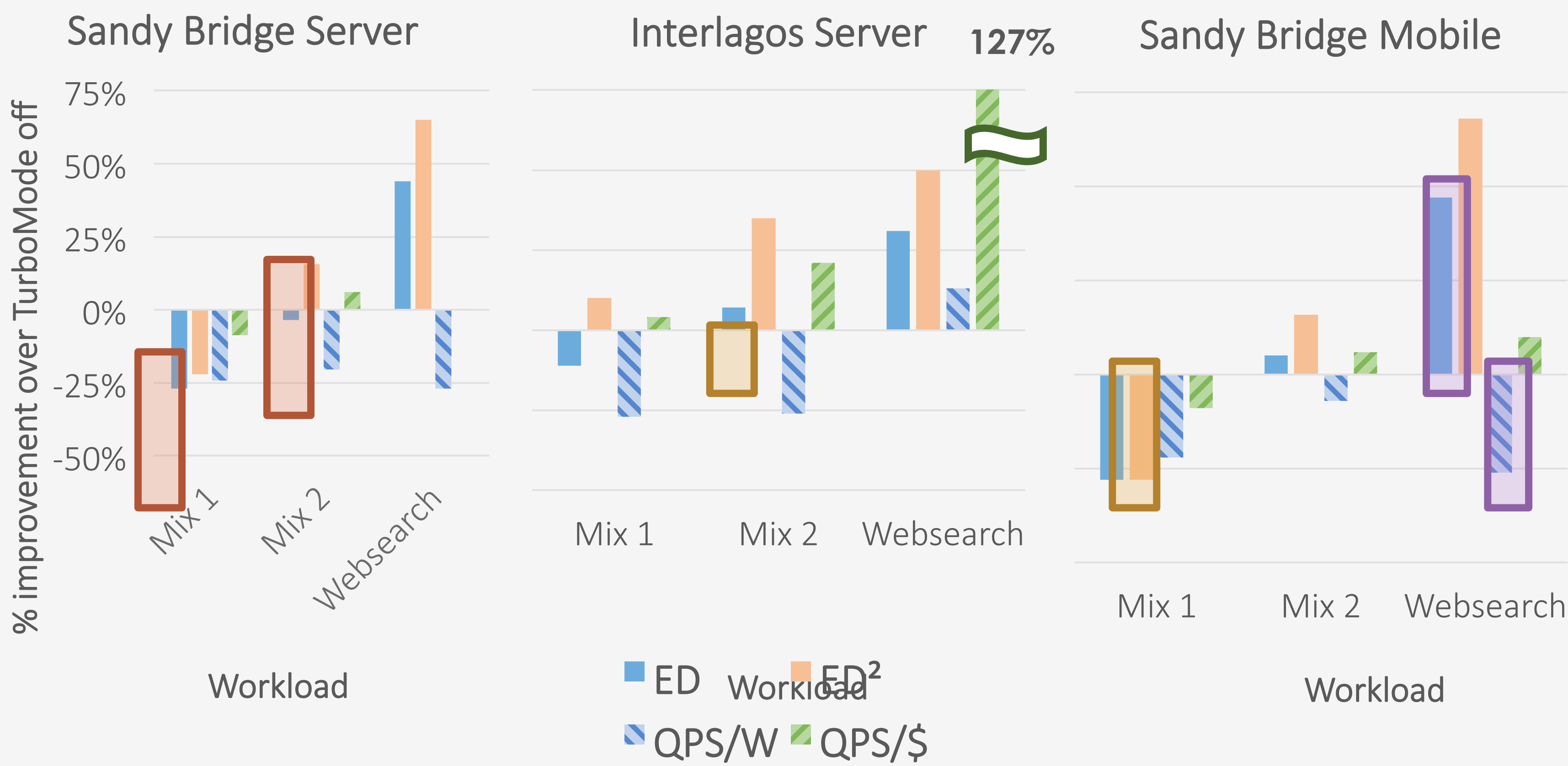
Evaluation Workloads

- Representative of multiple domains
- CPU, memory, and IO workloads

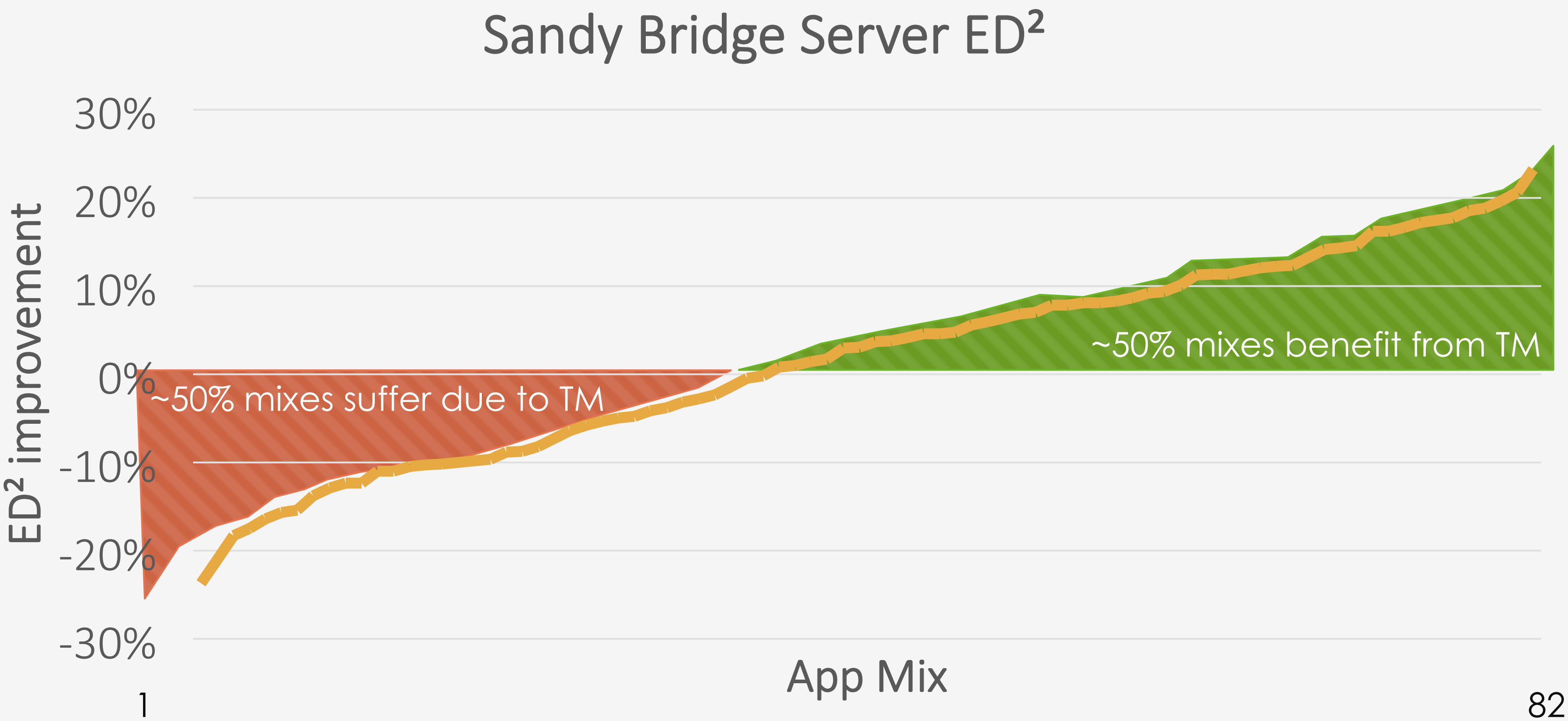
- Single-threaded SpecCPU benchmarks
- Multi-programmed SpecCPU mixes
- Multi-threaded PARSEC
- Enterprise SPECpower_ssj2008
- Websearch

} **>100 configs**

Observation: No Optimal On/Off Setting



Observation: TM leads to High Variance on Efficiency



Characterization Analysis

- TurboMode mostly benefits CPU bound workloads
  - Boost in performance and efficiency from higher frequency
  - SpecCPU mixes of CPU-intensive workloads, SpecPower, websearch, …
- TurboMode ineffective when memory/IO bound
  - Interference on memory/IO really aggravates this
  - Small/no performance gain, high energy waste with higher frequency
  - SpecCPU mixes of memory-intensive workloads, canneal, streamcluster, …
- Applications have multiple phases
  - CPU bound vs. memory/IO bound
  - SpecCPU mixes

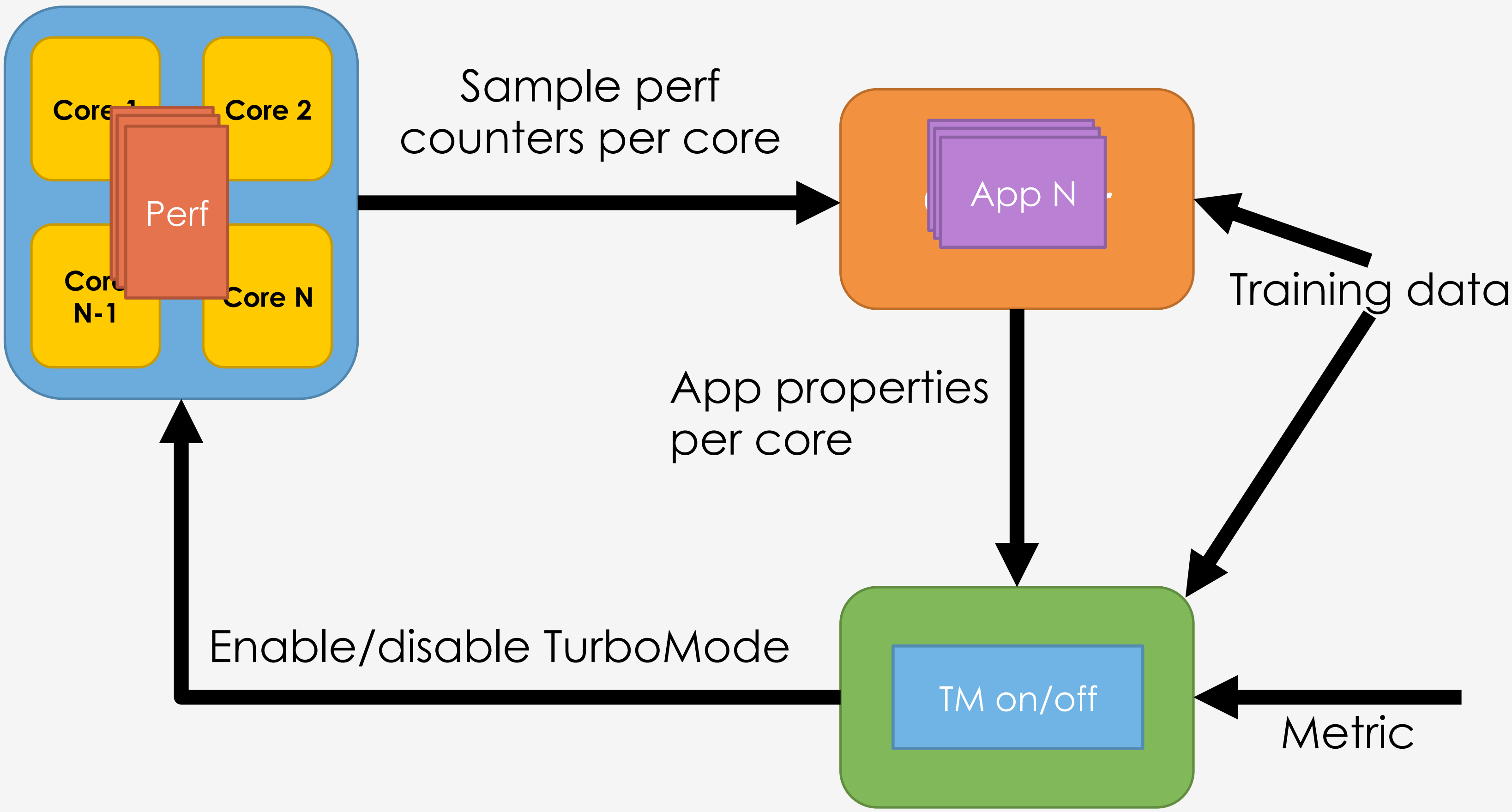
TurboMode Control

- Naïve TM control
  - Always off: miss boost on CPU bound applications
  - Always on: suffer inefficiency on interference-bound applications
- Need dynamic TM control
  - Understands applications running and metric of interest
  - Predicts optimal setting (on/off), adjust dynamically to phases
  - No a priori knowledge of applications, no new hardware needed

Predictive Model for TurboMode

- **Idea:** use runtime info to dynamically predict TM benefits
- Focus primarily on detecting memory interference
  - Build predictive model based on performance counters
  - Use performance counters & model to predict interference severity
  - If too severe, turn off TurboMode

Autoturbo: Predictive Control for TurboMode



Training the Predictive Model

Raw training data

- Single SpecCPU, TurboMode on
- Single SpecCPU, TurboMode off
- Single SpecCPU +stream, TurboMode on
- Single SpecCPU +stream, TurboMode off

Feature selection

Model selection

Naïve Bayes	**85%**
Logistic Regression	**81%**
Nearest Neighbors	**73%**
Decision Tree	**75%**

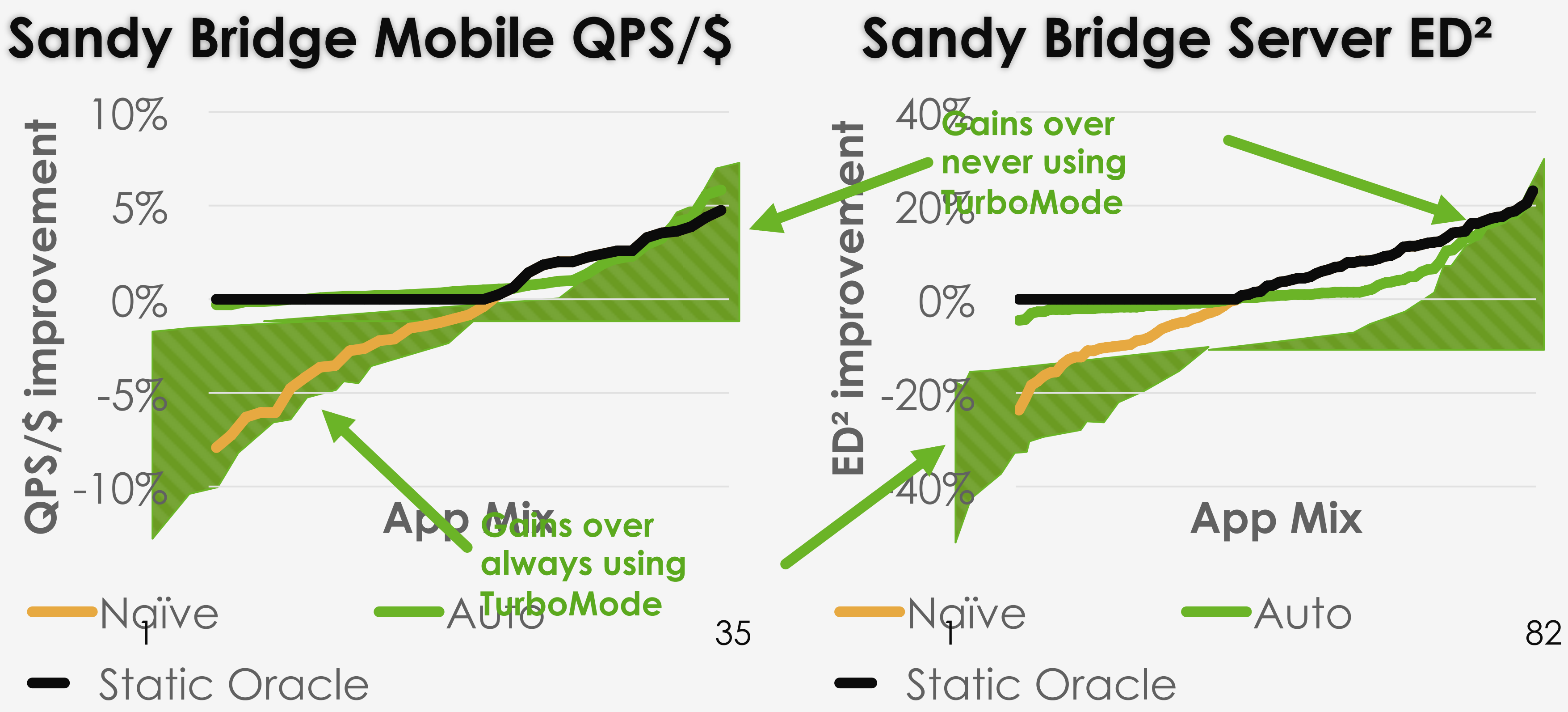
Model Validation

- **Model accuracy**: ~90% on cross-validation
- Best counters: those that indicate memory-bound workload
  - **SBServer/SBMobile**: % cycles with outstanding memory requests, …
  - **ILServer**: L2 MPKI, # requests to memory/instruction, …
- CPU/thermal intensity counters don't correlate strongly!
  - E.g., floating-point intensity counters

Autoturbo Evaluation

- Used **autoturbo** in conjunction with workloads
  - Evaluation workloads are apps other than single-thread SpecCPU
- Measure efficiency metrics
- Compare against
  - **Baseline:** TurboMode is always off
  - **Naïve TM**: TurboMode is always on
  - **Static oracle**: TurboMode on if leads to benefit for the overall run

Autoturbo results



Autoturbo Analysis

- **Autoturbo** gets best of both worlds
  - Reduces cases where TM causes efficiency degradation
  - Keeps cases where TM leads to benefits
- **autoturbo** often disables TM even though it is beneficial
  - **Cause**: the interference predictor assumes worst case interference
- **autoturbo** beats the static oracle
  - **Cause**: **autoturbo** can take advantage of dynamism during the run

Conclusions

- TurboMode is useful but must be managed dynamically
- This work: dynamic TurboMode control
  - Predictive model for memory interference
  - Dynamic control with no hand-tuning needed
  - Eliminates efficiency drops, maintains efficiency gains of TurboMode
- Future work
  - Apply similar approach to manage advanced power settings

autoturbo dealing with a phase change